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Rocket-borne Measurement of Mid-latitude Airglow and Particle Precipitation*

by

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ABSTRACT
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A simultaneous measurement of mid-latitude night airglow and particle fluxes has been made with a Nike-Apache rocket fired from Wallops Island, Virginia near midnight and new moon in July 1964. The rocket carried two photometers, three geiger counters and two scintillators, and two magnetometers as aspect sensors. The experiment conclusively demonstrated with three independent techniques that mid-latitude 5577 Å night airglow is not excited by charged particle bombardment as is the case with auroras. First, the intensity of 3914 Å above 85 km was measured to be 5 rayleighs or less, whereas if energetic particles had produced the 400 rayleighs of 5577 Å observed they should have also produced about 200 rayleighs of 3914 Å, or more than forty times what was observed. Second, the altitude profile was measured with high precision, and with its peak at (94.5 ± 0.3) km and its half-width of (5.8 ± 0.3) km it was shown to be much narrower than would be produced by particle fluxes of various energy spectra and pitch-angle distributions. Third, the actual particle fluxes were measured, and they could have produced much less than 1 R of 5577 Å around the altitude where it was brightest. The results, therefore, prove that less than approximately three per cent of mid-latitude 5577 Å night airglow can be termed a permanent aurora. The 3914 Å photometer measured 5 R emitted above 85 km, but a zenith-equivalent brightness of 10 R when it viewed the emission edge-on. The difference of 5 R is shown to be just that which would be caused by cosmic radiation at altitudes below 30 km. The particle fluxes are shown to be somewhat less than the precipitated fluxes measured several years previously with satellites. A comment is made on the contamination of some measurements of galactic X-rays by such precipitated electrons and vice versa.

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INTRODUCTION

Among the mid-latitude ionospheric phenomena as yet imperfectly understood are the cause of night airglow and the sustenance of the night-time ionosphere. In the auroral zone a major cause of excitation of auroral light and high-altitude ionization is bombardment of the atmosphere by electrons with energy of order 10 kev. By analogy, a similar cause is sometimes invoked to explain the mid-latitude phenomena mentioned above. A comprehensive summary of the state of understanding was given recently by Dalgarno (1964). It is clear from that summary that there was a need for measurements at mid-latitudes both of the particle flux that bombards the atmosphere, and of the brightness of the ionized molecular nitrogen emission at 3914 Å. In this note we report a coordinated rocket-based measurement of both these quantities.

The problem of distinguishing auroral light from airglow light is in part sometimes a matter of mere semantics. As Chamberlain (1961) notes 'The most frustrating aspect of defining the airglow lies in distinguishing it from the aurora.' Chamberlain (1961) gives an excellent summary of the problem, and says that 'Any meaningful and valid distinction between aurora and airglow must eventually look to the cause of the excitation.' A principal cause of aurora is bombardment of the atmosphere by energetic particles and so the question arises whether airglow may have a similar cause.

O'Brien (1962) endeavoured to resolve this problem by satellite measurements at 1000 km altitude of the flux of precipitated particles i.e. of those particles whose trajectories would tend to carry them into the appreciable atmosphere to altitudes of 100 km or less, where bright airglow emissions occur. O'Brien (1962) found that the mid-latitude flux of precipitated electrons with energy $E_e \geq 40$ kev was of order 10^2 to 10^3 particles cm^{-2} sec^{-1}, corresponding to an energy flux of order 10^{-5} to 10^{-4} ergs cm^{-2} sec^{-1}. The typical airglow brightness of the principal emission at these same mid-latitudes, viz, that of atomic oxygen at 5577 Å, is about 250 rayleighs or 250 x 10^6 photons cm^{-2} sec^{-1}, (Chamberlain 1961), so this photon energy flux is about 10^{-3} ergs cm^{-2} sec^{-1} or at least an order of magnitude greater than the energy brought in by electrons with $E_e \geq 40$ kev. However, McIlwain (1960) and others have shown that most of the auroral energy is brought in by electrons with $E_e \sim 10$ kev rather than $E_e \geq 40$ kev. O'Brien (1962) found that the flux of precipitated electrons and protons with $E_e \geq 1$ kev was below the threshold of detectability of ~ 1 erg cm^{-2} sec^{-1}. McIlwain's (1960) auroral data showed that 1 erg cm^{-2} sec^{-1} would sustain only ~ 50 rayleighs of 5577 Å so that O'Brien (1962) judged it unlikely that such particles sustained mid-latitude 5577 Å airglow.

When O'Brien (1962) assumed that the electron spectrum at 1000 km altitude was independent of pitch-angle, he was able to deduce that the flux of precipitated electrons with $E_e \geq 1$ kev was of order 10^{-2} ergs cm^{-2} sec^{-1} or less, so it was even more unlikely that such particles sustained this airglow. But he was unable to prove this assumption. Furthermore, the possibility existed (although it appears to us to be unlikely) that an unknown mechanism accelerates electrons to kilovolt energies between the satellite altitude of 1000 km and the airglow altitude of 100 km. Clearly what was necessary to resolve the matter was an <u>in situ</u> measurement of particle flux at mid-latitudes. We report such a measurement here and show that it confirms that mid-latitude 5577 Å is not excited by particle bombardment.

Another method of approaching this problem is to make a spectral analysis of airglow and aurora. The principal comparison is between the atomic oxygen line at 5577 Å and the molecular nitrogen band at 3914 Å. The oxygen emission requires about 4 ev for excitation, but the N_2^+ about 19 ev (Chamberlain 1961). The relevance of this comparison is that bombardment by electrons with energies of kilovolts can easily excite both emissions, but if airglow is of chemical origin (as often suggested), it will be much easier to provide processes that give 4 ev rather than $\sim$ 19 ev. The two emissions are of comparable brightness in aurora (we have recently measured the ratio with rocket flights into aurora) but their relative intensity in airglow is uncertain (see Chamberlain 1961). As reported by Dalgarno (1964), it is agreed that the 3914 Å airglow intensity is below 60 R, but he comments that it might be only a few rayleighs. It is very difficult to measure 3914 Å airglow from the ground because starlight brightness contributes $\sim$ 1 R/Å or some tens of rayleighs through most photometric filter arrays, and because with the alternative technique of photographic emulsions there is a reciprocity failure at low light levels that makes spectroscopic quantitative comparisons uncertain (see Roach, McCaulley, Marovich, and Purdy 1960). We have therefore flown two photometers, one sensitive to 5577 Å and the other to 3914 Å, to altitudes of over 160 km so that they passed through the airglow layer and saw only starlight above. We report the results in this note and set an upper limit to 3914 Å airglow at mid-latitudes of 5 rayleighs. From this we conclude again that particle bombardment is a negligible source of airglow. This experiment therefore resolves Chamberlain's speculation 'It seems not impossible that λ 3914 Å may appear faint in the nightglow as a result of particle bombardment, perhaps constituting a weak permanent aurora emanating primarily from the E region.'

In this airglow-aurora controversy which we endeavor to resolve in this note, it is of ironical interest to draw the reader's attention to Fig. 9.3 of Chamberlain (1961). This figure purports to show the 'nightglow spectrum, 3720-4100 Å.' However it shows intense bands of N_2 and N_2^+, including one at 3914 Å, and the caption includes the notation that these are 'auroral contamination.'

In this note then, we will show by a coordinated rocket-borne measurement of particle fluxes and of the airglow spectral features that aurora and mid-latitude 5577 Å night airglow do not have a common cause, and that less than $\sim$ three per cent of the latter can be regarded as a permanent aurora. We also derive values of particle ionization of the upper atmosphere of relevance to the problem of sustenance of the night-time ionosphere at mid-latitudes (see Dalgarno 1964).

EXPERIMENTAL DETAILS

A series of five Nike-Apache rocket flights was carried out by the newly-formed group in the Department of Space Science of Rice University in the first half of 1964. The first flight of an 'airglow' payload at Wallops Island in January 1964 was abortive due to rocket malfunction. The rocket spun at only 1 rps rather than the nominal 5-6 rps, and so it yawed very greatly and achieved a peak altitude of only 90 km rather than the nominal 130 to 150 km. Three 'auroral' payloads then carried 5577 Å and 3914 Å photometers, geiger counters, scintillation counters and magnetometers successfully into three auroral events at Fort Churchill in March 1964. The results of these auroral flights will be reported in detail elsewhere, but they will be used in this note as a basic source of information on auroral characteristics such as the ratio of intensities of 5577 Å and 3914 Å. The fifth payload was instrumented for airglow studies, and successfully fired at Wallops Island, Virginia [Geographic Latitude 37° 50', Geographic Longitude 75° 29'W, L = 2.6]. Results from this fifth payload are reported here.

The Nike-Apache payload [NASA 14.154 UE Code-name Sammy 2] is listed in Table 1. If we take the rocket axis pointed up at launch as defining an angle $\theta = 0°$, then there were two photometers pointed at $\theta = 0°$. These had narrow-band interference filters with peak transmissions near 5577 Å and 3914 Å and transmissions of 16% and 27% at these wavelengths respectively. The equivalent bandwidths for continuum transmission were 9.7 Å x 100% and 13.7 Å x 100% respectively. The photometers were of similar design to those used in satellite studies of auroras (O'Brien and Taylor 1964), with Ascop 541 A

TABLE 1

Payload Complement Wallops Island

July 9, 1964

Instrument	Orientation*	Opening Angle	Geometric Factor	Detectable Radiation
Photometer 1	$\theta = 0°$	$\pm$ 4.5°	.28 cm^2 sterad	5577 Å Light
Photometer 2	$\theta = 0°$	$\pm$ 4.5°	.28 cm^2 sterad	3914 Å Light
8001 Geiger	$\theta = 0°$	$\pm$ 33°	6.7 cm^2 sterad for 4.0 mg cm^{-2}	$E_e \gtrsim 100$ kev $E_p \gtrsim 1$ Mev X-rays
6213 Geiger	$\theta = 70°$	$\pm$ 9.5°	1.9 x 10^{-2} cm^2 sterad for 1.2 mg cm^{-2}	$E_e \geq 40$ kev $E_p \geq 500$ kev X-rays
6213 Geiger with magnet	$\theta = 70°$	$\pm$ 8.5°	1.5 x 10^{-2} cm^2 sterad for 1.2 mg cm^{-2}	$E_e \geq 1.5$ Mev $E_p \geq 500$ kev X-rays
Scintillator 1 Scintillator 2	$\theta = 70°$	$\pm$ 17°	0.60 cm^2 sterad	$E_e \gtrsim 5$ kev $E_p \gtrsim 15$ kev
Magnetometers	$\theta = 0°$ and $\theta = 70°$	- -	- -	Aspect

*Orientation is referred to the rocket axis, and $\theta = 0°$ is the forward or up direction.

photomultipliers operated at 2500 volts, and with the photomultiplier current converted by a 'tickled' neon-flasher circuit to a digital output which supplied a scaler with outputs at 2^1 and 2^5 counts. These outputs modulated the sub-carriers directly. Thus, the photometer outputs consisted of changes of state of a binary system, and the time between changes of state was inversely proportional to the light intensity. This provides a linear system with very high resolution, and so permits a measure of the altitude profile of the airglow with high precision. The field of view of each photometer was $\pm$ 4.5°.

Also pointed at $\theta = 0°$, but with an opening angle of $\pm 33°$ was an Eon type 8001 pancake geiger tube. The large area thin mica window required a grid of stainless steel for support, and the area over which the effective window thickness was 4.0 mg cm^{-2} was 6.7 cm^2, while another 9.8 cm^2 of the front was covered with stainless steel about 1 g cm^{-2} thick. This very large geiger tube was provided so as to detect the anticipated small flux of electrons with energies above $\sim$ 100 kev and protons with energies above $\sim$ 1 Mev with a geometric factor of 6.7 cm^2 sterad. Its efficiency to X-rays of energy $\sim$ 1 to 10 kev of possible galactic origin (Giacconi et al. 1962) was measured prior to launch to be $\sim$ 1 to 10% [L. Westerlund, private communication].

Two thin-windowed (1.2 mg cm^{-2} of mica) Eon type 6213 geiger tubes pointed parallel to one another at $\theta = 70°$. These had opening angles of $\pm$ 9.5° and $\pm$ 8.5° and were otherwise identical except that the second had a broom magnet to exclude electrons with energies below $\sim$ 1.5 Mev. The open 6213 geiger was sensitive to electrons with energies E_e above 40 kev and protons with E_p > 500 kev. Similar tubes have been used in extensive satellite studies of electron precipitation (O'Brien 1962, 1964) and in the auroral series mentioned above.

Pointed parallel to the two geiger tubes were two d-c scintillators with opening angles of ± 17°. These used Ascop 541 A photomultipliers, and the scintillator in each case was a thin (13 mg cm^{-2}) sheet of Pilot B plastic, on the front of which was evaporated $\sim 30 \mu g\ cm^{-2}$ of aluminum to attenuate starlight and airglow light. One scintillator used an analogue-to-digital converter as in the photometers. The other used an electrometer so as to achieve spin resolution. Once every sixteen seconds a disc of lucite $\sim$ 0.5 g cm^{-2} thick was swung by a rotary solenoid in front of the analogue scintillator, thereby excluding electrons and protons with energies below $\sim$ 1 Mev and $\sim$ 20 Mev respectively, but permitting the passage of light from the stars and airglow.

Two Schonstedt flux-gate magnetometers were oriented so as to be parallel to the payload axis and the scintillators respectively. These were used to give aspect information. Thermistors were mounted in the scintillators and the 5577 Å photometer to monitor the temperature during flight. The effective temperature change was less than 3 C° during portions of useful data and so it was negligible.

The instrumentation was exposed 53 seconds after lift-off at an altitude of 56 km when a shaped-charge cut through the cylinder of the structure and the spring-loaded nose-cone and shell were removed as one piece. Radar tracking of the removed section showed that it then fell about 1 km behind and below the rocket by peak altitude and it could not have appreciably interfered with the view of any detector thereafter.

The rocket was fired at 0413 Z July 9, 1964 within a few hours of the new moon and about forty-five minutes before local midnight. Solar and lunar light were thereby minimized and effectively negligible. The sky was free of clouds, and ground-based photometers with interference filters with peak transmission at 6300 Å, 5577 Å, 5300 Å, and 3914 Å monitored airglow and stellar brightness from the region viewed by rocket-borne photometers. The rocket reached a peak altitude of 167 km and the altitude at a given time was measured by radar to an estimated accuracy of better than 0.1 km. The rocket spun at $\sim$ 5 rps and maintained stability with a yaw period of $\sim$ 40 seconds and an amplitude of $\sim \pm 5°$ until it returned to an altitude of $\sim$ 80 km after $\sim$ 340 seconds. It then slowly turned over and spun down into the atmosphere. As we will see below, this attitude behavior was excellent in permitting good photometric observations of airglow at near-normal and also edge-on incidence, as well as observations of starlight alone above the airglow layer.

EXPERIMENTAL RESULTS

Photometers

The counting rates of the two photometers are shown for the most interesting portion of the flight in Fig. 1. During the ascent phase there was significant corona contamination of the data, but around apogee and during the descent down to ~ 70 km the records are very clear. Fig. 1 shows four stages of response of the 5577 Å photometer. In the first (A) at altitudes above 105 km, it looked up and detected only starlight. During the second (B) it looked up and fell through the 5577 Å airglow layer between altitudes of 105 and 85 km, detecting a steadily-increasing brightness until it reached an altitude of ~ 85 km when all the airglow was above it. It continued in this stage (C), and then it turned over (as shown by the axial magnetometer) and viewed the airglow edge-on, so that the apparent brightness was greatly enhanced (stage D). Then it viewed down towards the ground and shortly thereafter heated and telemetry was lost. The details of phase A are shown in Fig. 2 as the two photometers scanned over the stars with a yaw rate of 40 secs. Approximately three per cent of the points plotted in these figures deviate significantly from the remainder. These are due to non-uniform triggering of the high-impedance flasher circuit and they are negligible because of the very small scatter of the great majority of the points.

The 5577 A photometer records in phase B can be analysed in the usual way, and the differential of the curve taken to yield the altitude profile of emission of 5577 A airglow as shown in Fig. 3. The peak emission was at 94.5 km altitude, and the width at half-maximum was only 5.8 km. It is difficult to estimate the accuracy of the profile, but by comparison of curves fitted by five independent observers we derived a mean value of (94.5 ± 0.3)km for the peak of the emission, and (5.8 ± 0.3)km for the width at half-peak, where the error ranges include all five estimates.

The integrated 5577 Å emission was estimated from calibration in flight using starlight (Roach 1956) and from the ground-based photometer to be (400 ± 100) rayleighs.

As shown in Fig. 1, the 3914 Å photometer did not see a clearly-defined airglow layer as it dropped down through phase B and C, but it did see a significant enhancement over starlight when it viewed the emission edge-on in phase D. From phases A, B, and C an upper limit can be set to the 3914 Å brightness above 85 km as equivalent to 0.15 counts per second. When the dark current contribution (0.16 ± 0.01 counts per second) is subtracted from airglow plus starlight detected by the 3914 Å photometer, this implies that the 3914 Å signal through the filter is less than (0.15/1.19) x 100% or less than 13% of the starlight (see Fig. 2) passed by the filter. The mean starlight signal deduced from data of Roach (1956) is (7.6×10^5) photons cm^{-2} sec^{-1} $Å^{-1}$. The 3914 Å filter had an equivalent width of 13.7 Å x 100%, so that the starlight signal was equivalent to 10.4 rayleighs incident on the front of the filter. The mean transmission of 3914 Å was 27%. Hence the <u>upper limit</u> to the total brightness of 3914 Å above 85 km as derived from phases A, B, and C is (39 x .13) = 5 R.

An estimate of 3914 Å intensity can be derived also from phase D, when both photometers viewed the airglow layer edge-on. The consequent enhanced brightness is best estimated from the 5577 Å photometer whose axis was parallel to that of the 3914 Å photometer and whose field of view was identical. After subtraction of starlight and dark current from the 5577 Å photometer, the edge-on enhancement was calculated to be (44/3.8) = 12 to 1. The 3914 Å peak rate minus the starlight and dark current was about 3.4 counts per second so we would deduce that the rate at normal incidence to the layer should be about 0.28 counts per second. This is equivalent to 10 rayleighs of 3914 Å corrected to viewing of the zenith.

Thus the 3914 Å zenith-equivalent brightness estimated from the edge-on viewing is 10 R, or about twice that deduced from normal-incidence viewing of the region above ~ 85 km. One obvious explanation is that the remaining 5 R is emitted at altitudes below 85 km. If one considers the excitation of 3914 Å by cosmic rays with a flux of ~ 2 particles cm^{-2} sec^{-1} with an average energy of 5 Bev, then these should produce about 5 R of 3914 Å. Most of this will be emitted in the dense atmosphere below ~ 30 km, i.e. far below 85 km. Due to atmospheric extinction and scattering, and perhaps absorption by clouds at very low altitudes, and to the different geometry of the edge-on enhancement, the exact agreement between the observed intensity of 5 R from below 85 km and the predicted cosmic ray contribution of 5 R is quite remarkable.

We conclude, therefore, that about 5 R of airglow was detected by the 3914 Å photometer above ~ 85 km, and about the same amount below that altitude. Whether the high-altitude portion was actually N_2^+ at 3914 Å or a continuum emission is discussed below.

Particle Detectors

The large-area geiger tube type 8001 gave the most precise information on the particle fluxes. As expected from earlier satellite observations (O'Brien 1962), the particle fluxes were very small. Accordingly, cosmic rays set the lower limit to the detectable particle fluxes for the three geiger tubes, and starlight plus airglow set the lower limit for the two scintillators.

The average counting rate of the large area geiger at altitudes above 100 km was (38.3 ± 0.5) counts per second. The rate below ~ 80 km due to cosmic rays was (19 ± 1) counts per second. On the first Wallops Island flight in January 1964 a similar geiger gave (18.4 ± 0.4) counts per second above the Pfotzer maximum but below 80 km. For cosmic rays the omni-directional geometric factor of the detector was ~ 12 cm^2, so this implies that the cosmic ray and albedo flux above Wallops Island was 1.6 particles cm^{-2} sec^{-1}.

There was thus a residual flux that gave (20 ± 1) counts per second but was absorbed at altitudes between ~ 80 km and 100 km (Fig. 4). If these were penetrating particles detected with essentially unity efficiency, the corresponding flux was (2.8 ± 0.2) particles cm^{-2} sec^{-1} sterad^{-1}, or effectively (18 ± 1) particles cm^{-2} sec^{-1} if the flux was isotropic over the upper hemisphere. If the flux consisted of galactic X-rays over the entire field of view with energy ~ 1 to 10 kev (Giacconi et al. 1962, Gursky et al. 1963) then the flux deduced from preflight X-ray calibrations was $\sim 10^2$ photons cm^{-2} sec^{-1} sterad^{-1} (Courtesy L. Westerlund).

To distinguish between X-rays and energetic electrons we studied the altitude profile of the 8001 geiger tube (Fig. 4) and also the relative counting rates of the two thin-windowed type 6213 geigers. Both of the 6213 geigers would detect X-rays equally well, but the one with the broom magnet would not detect electrons if their energy was less than $\sim$ 1.5 Mev (D. Criswell, private communication). The results are summarised in Table 2.

The two type 6213 tubes at altitudes above 100 km gave counting rates of (0.61 ± 0.05) counts per second and (0.23 ± 0.03) counts per second for the open and the broom instrument respectively. The rates to be expected from cosmic rays alone were predicted by taking the in-flight rate of the 8001 geiger tube and normalising for the relative omnidirectional geometric factors as derived from sea-level cosmic ray calibrations. The cosmic ray rates are predicted to be (0.47 ± .02) and (0.22 ± 0.01) counts per second for the open and the broom 6213 geiger tubes respectively. Thus the residual rates not due to cosmic rays are about (0.14 ± 0.05) and (0.01 ± 0.03) counts per second respectively.

From these data, admittedly of low statistical accuracy, we draw the following conclusions:

(1) the 6213 broom geiger tube response was consistent with its detection of cosmic rays alone.

(2) the open 6213 geiger tube detected particles other than cosmic rays in a flux of (7 ± 2) particles cm^{-2} sec^{-1} $sterad^{-1}$. Since these were not detected by the geiger tube with the broom magnet, these particles could not have been X-rays, or protons, or electrons with energy $E_e \gtrsim 1$ Mev. They must therefore have been electrons with energy $E_e \geq 40$ kev. On the assumption of isotropy over the upper hemisphere, the corresponding flux was ~ 40 cm^{-2} sec^{-1}.

With this measured flux of electrons with $E_e \geq 40$ kev of ~ 7 particles cm^{-2} sec^{-1} $sterad^{-1}$, we would expect to see a flux of ~ 3 and 0.1 particles cm^{-2} sec^{-1} $sterad^{-1}$ for electrons with $E_e \geq 100$ kev and $E_e \gtrsim 1$ Mev if the spectrum was like that of Van Allen electrons trapped at $L \sim 2.6$ (see Cladis et al. 1961). Such higher-energy electrons would produce ~ 20 counts per second in the 8001 geiger and $\sim (0.001)$ counts per second in the 6213 with broom. These rates are to be compared with those observed (over and above cosmic ray rates) to be $\sim (19 \pm 1)$ and (0.01 ± 0.03) counts per second respectively. Considering the extreme variability of the outer-zone electron spectrum (eg. see Frank et al. 1964) and the relatively poor statistics these results are in remarkably close agreement.

We therefore conclude from analysis of the three geiger tube rates that there was a precipitated flux of electrons with $E_e \gtrsim 40$ kev of order (40 ± 10) particles cm^{-2} sec^{-1} whose energy spectrum is consistent with their origin in the Van Allen radiation zone. The spectral analysis is not accurate enough to <u>prove</u> that these electrons were formerly Van Allen electrons, and since it is not known what mechanisms cause such precipitation it is not clear that one should even expect the spectrum of precipitated electrons at $L \sim 2.6$ to be like that of Van Allen electrons there (see O'Brien 1964).

TABLE 2

Geiger Counter Rates above 100 km
at Wallops Island
and background data

	Rate above 100 km	Measured Cosmic ray Rate in-flight	Predicted Cosmic ray Rate	Difference [X-rays or electrons]
8001	38.3 ± 0.5	19.0 ± 1	20.6 ± 1	(19 ± 1)
6213	0.61 ± 0.05	- -	0.47 ± 0.02	(0.14 ± 0.05)
6213 B	0.23 ± 0.03	- -	0.22 ± 0.01	(0.01 ± 0.03)

Errors are Poissonian standard deviations and all rates are counts per second.

Scintillation Detectors

The scintillator crystals were coated with aluminum so that starlight was attenuated by factors of $\sim 3 \times 10^4$ for the analogue and digital scintillators. Even so, the major contribution to their signals in flight came from airglow and starlight rather than from particle fluxes. This was proved by comparison of the analogue output with and without the transparent lucite shield over the detector. This shield transmits visible light, but absorbs particles of energy $E_e \leq 1$ Mev and $E_p < 20$ Mev such as are of importance here. The scintillators, in the presence of such contamination, merely set an upper limit of ~ 1 erg cm^{-2} sec^{-1} sterad^{-1} to the total energy flux of electrons with $E_e \gtrsim 5$ kev and protons with $E_p \gtrsim 15$ kev. Since with other instrumentation, particularly the 3914 Å photometer, we can set an upper limit that is more than one hundred times less than the above, the scintillators are not used further in this analysis.

COMPARISON WITH OTHER EXPERIMENTS

5577 Å Altitude Profile

Several measurements have been made of the altitude profile of airglow 5577 Å. The results of four flights at White Sands as summarized by Packer (1961) showed the peak emission occurred at altitudes between 97 and 99 km, with the average at 97 km. By contrast this experiment found an altitude of (94.5 ± 0.3) km. The White Sands profiles refer to a geographic latitude 32°24'N, longitude 106°25'W and the four published profiles (Packer 1961) were obtained within about three hours of local midnight, over the years between 1955 and 1959. Our profile was obtained at Wallops Island, geographic latitude 37°51'N, longitude 75°29'W, within forty-five minutes of local midnight in July 1964. There are therefore a sufficient number of parameters altered between the N.R.L. White Sands experiments and ours at Wallops Island that, while attention is drawn to the significant difference between the altitudes of peak emission of 5577 Å, we do not speculate on the cause of this difference.

The brightness of the 5577 Å emission determined in phase C of Fig. 1 was ~ (400 ± 100) rayleighs. This is well within the range of intensities observed at mid-latitudes (Roach et al. 1959).

3914 Å Intensity

No previous rocket-borne measurements of 3914 Å or other N_2^+ bands in the night airglow are known to us. We therefore must make comparison here with ground-based measurements. As mentioned in the Introduction, these are very difficult to make accurately because starlight provides a substantial contamination. The results have been reviewed recently by Dalgarno (1964). Roach placed an upper limit of 60 R on the mid-latitude intensity of 3914 Å airglow. Galperin's measurement of 4278 Å when applied to 3914 Å yields an intensity of less than 5 R of 3914 Å at a magnetic latitude of 51°N, essentially the same latitude as Wallops Island. Lytle and Hunten (1962) found at a magnetic latitude of 60.5°N that the 3914 Å intensity was ~ 30 R in 1960 and probably less than ~ 20 R in 1961. Maartense and Hunten (1963) reported that at the same location in 1962 they found about 60 R of which perhaps 20 R was due to background from mercury lights. Moore (1963) found above China Lake, California an upper limit of 28 R, uncorrected for starlight or extinction effects.

As discussed by Roach et al. (1960) estimates of 3914 Å airglow from spectroscopic exposures are uncertain because of reciprocity failure of the photographic emulsions at low light intensities. The Canadian spectrophotometer does not suffer from this disadvantage, and so here the measurements of Hunten and his co-workers are adopted as giving the most accurate estimate from ground-based measurements. On the average they found, at a magnetic latitude of 60.5°N, a permanent airglow intensity of ~ 30 to 60 R, or on the average, a 3914 Å intensity of about one fifth the 5577 Å airglow.

By contrast, at the Wallops Island magnetic latitude of 51°N, we find a 3914 Å intensity above 85 km of 5 R or less. Even if all the airglow detected by this photometer above 85 km was N_2^+ 3914 Å, i.e. if the airglow continuum in this spectral region was negligible, we would then place the ratio of intensities $\frac{Q\ (5577\ \text{Å})}{Q\ (3914\ \text{Å})}$ as greater than eighty to one, almost twenty times more than that found by Hunten and co-workers.

It is of interest to compare this ratio of 5577 Å and 3914 Å intensities with that found in auroras. The ratio in auroras is generally stated to be between two and unity (Chamberlain 1961, Dalgarno 1964). Estimation from ground-based measurements is subject to some uncertainty because of the very different extinction coefficients of the two wavelengths. In our three Nike-Apache auroral flights in March 1964 the ratio was about 2 to 1 (to be published). Thus we conclude from comparison of our Wallops Island and Fort Churchill data that in the permanent mid-latitude airglow above 85 km the relative intensity of 3914 Å to 5577 Å is only one-fortieth (or less) of what it would be in an aurora. One might conclude that less than three per cent of the mid-latitude 5577 Å night airglow can be considered as a permanent aurora.

As discussed above, the estimated zenith-equivalent intensity of 3914 Å derived from the edge-on view (phase D of Fig. 1) was 10 R, whereas that from phases A, B, and C was 5 R from above 85 km. We concluded that the remaining 5 R was generated at altitudes below 85 km, and we showed above that this is the intensity that would be expected from cosmic ray bombardment, with most of the emission coming from below $\sim$ 30 km. This cosmic ray contribution to 3914 Å has not been generally recognized, but it does constitute a minimum intensity for ground-based observations (Meinel 1953). Moore (1963) found enhanced 3914 Å emissions from lightning flashes, with some tens of rayleighs persisting for an appreciable fraction of a second. It is possible that some of the low-altitude 5 R zenith-equivalent 3914 Å detected in phase D of Fig. 1 was caused by lightning on the horizon, although as shown above it can be adequately explained as being caused by cosmic radiation.

The only previous high-altitude measurements of 3914 Å known to us were made by O'Brien and Taylor (1964) with the satellite Injun 3. The 3914 Å photometer on that satellite had a dark current noise equivalent to about 30 R of 3914 Å because of its exposure to Starfish artificial radiation. Some ninety per cent of the intensities measured at an invariant latitude of $\sim 60°$ were below this value, and this is in agreement with Hunten's data discussed above. Our measurements with rockets at Fort Churchill also serve to verify that the calibrations of the 3914 Å photometer used by O'Brien and Taylor (1964) in their auroral studies of 3914 Å and 5577 Å were valid to a factor of about two.

Particle Fluxes

There are no previous relevant night-time measurements of particle fluxes at these altitudes and near this latitude known to us. The most relevant comparable measurements were those made by O'Brien (1962) and O'Brien (1964) with Anton type 213 geiger tubes in satellites Injun 1 and Injun 3 respectively. The flux found early in 1963 (O'Brien 1963) gave some indication of being less than that found late in 1961 (O'Brien 1962), so the more recent values are used for this comparison here. These found a precipitated flux of $E_e \gtrsim 40$ kev electrons at $L \sim 2.5$ (the location of Wallops Island) of between 10^2 and 10^3 particles cm^{-2} sec^{-1} of electrons with $E_e \geq 40$ kev.

By comparison, in this rocket experiment the flux of electrons with $E_e \geq 40$ kev impinging on the atmosphere over Wallops Island was found to be about (40 ± 10) particles cm^{-2} sec^{-1}. This is one to two orders of magnitude less than the average of the satellite-based measurements, and somewhat outside the wide range of values encountered by the satellites at different times (see Fig. 16 of O'Brien 1964). Whether this lower flux is related to the lower solar activity (which was near minimum in July 1964) or whether it is just an unusually small flux cannot be determined here. If it was an unusually small flux, then the 3914 Å brightness of less than 5 R may also be unusually small. But even so the need for a non-auroral source of airglow 5577 Å has been conclusively demonstrated.

As mentioned above, the electron-energy spectrum derived from the three different geiger-tubes on the rocket is reasonably consistant with what might be expected if the particles were formerly Van Allen or trapped electrons. There are such significant temporal changes in the trapped spectrum that this comparison cannot be made very rigorously. Nevertheless it is of interest here because of the possible information it may provide about the charged-particle contamination of galactic X-ray studies made with rocket-borne geiger tubes by Giacconi and others (1962). This feature is discussed in a separate section below.

Even such weak precipitation as observed on this occasion represents a significant drainage on the Van Allen radiation. If it continued at this rate even when the unknown source of Van Allen radiation was stopped, then the zone would take only several weeks to empty.

DISCUSSION OF THE ALTITUDE PROFILE OF 5577 Å

It can be demonstrated that incident electrons do not excite the 5577 Å airglow by making a comparison of the altitude profile of the airglow and the altitude profile that might be produced from bombardment by conceivable particle fluxes. Over the altitude range above $\sim$ 80 km collisional deactivation of the long-lived O (^1S) parent state of 5577 Å is apparently negligible (Chamberlain 1961). Accordingly on the assumption of a constant relative composition of the atmosphere over the altitude range of interest of $\sim$ 85 km to $\sim$ 120 km, we can take the relative production of 5577 Å at a given altitude as being proportional to the ionization at that altitude (The effect of the actual changes in relative composition with altitude is examined below.)

Rees (1963) has calculated the altitude profiles of ionization produced by electron fluxes of various energies and angular distributions. One of the most pronounced features of the 5577 Å profile is its thinness, as summarized in Table 3 and shown in Fig. 3. It is apparent that the thinnest ionization profile will be produced by a monoenergetic flux of electrons incident on the top of the atmosphere. From the graphs presented by Rees (1963), it can be seen that in order to produce maximum ionization at the airglow peak of 94 to 95 km one requires electron energies of about 40 kev. (Such electrons are efficiently detected by our type 6213 geiger tube, which found fewer than $\sim$ 100 particles cm^{-2} sec^{-1} above the airglow. These would have produced less than $\sim 10^{-2}$ rayleighs of 3914 Å or 5577 Å). The electron flux detected was so small that no information was gained about its angular distribution during this flight. O'Brien (1964) has found that above auroras the electron fluxes with $E_e > 40$ kev tend to approach isotropy over the upper hemisphere. So isotropy is assumed for this rocket flight, although clearly such an assumption cannot be justified. If we wish for a very thin altitude profile of ionization then a unidirectional flux directed parallel to the magnetic field vector $\vec{B}$ might be chosen. Since any precipitated electrons over Wallops Island are likely to be former Van Allen electrons scattered in some way from their trapped trajectories, it seems likely that their pitch angle distribution will be more likely to have a maximum perpendicular to $\vec{B}$ (i.e. at $\alpha = 90°$) than parallel to $\vec{B}$ (i.e. at $\alpha = 0°$). So an isotropic distribution over $0° \leq \alpha \leq 90°$ appears a reasonable compromise.

From figures presented by Rees (1963) we, therefore, derived the altitude profile of energy loss of a monoenergetic beam of 40 kev electrons incident isotropically on the upper atmosphere. The thickness of this profile is compared in Table 3 with the thickness of the 5577 Å altitude profile shown in Fig. 3. It is apparent that the energy-loss profile is much broader than the 5577 Å profile. For example, the thickness at half-maximum is about 11.6 km for the energy loss and only 5.8 km for the 5577 Å.

Furthermore, by the assumption that the 5577 Å intensity is proportional to the total ionization the thickness of the particle-produced altitude profile has actually been underestimated at high altitudes above ~ 90 km. The relative proportion of atomic oxygen in the atmosphere increases very rapidly above ~ 70 km [eg. see Chamberlain (1961) model atmosphere] so that proportionally more and more of the total energy loss of the particles goes to the atomic oxygen and hence to any 5577 Å. Whereas, for example, at 90 km the ratio of oxygen atoms to nitrogen molecules (the most abundant constituent) is about 1 to 70, at 100 km it is about 1 to 2.5, at 110 km about 1 to 2, and so on.

It is therefore clear that the accurate altitude profile of 5577 Å shown in Fig. 3 is of itself sufficient to show that it is not excited by particle bombardment. When combined with the 3914 Å and particle measurements the matter is resolved beyond question.

TABLE 3

Comparison of Altitude Profiles of 5577 Å

and

Energy Loss of 40 kev Isotropic Electrons

Intensity Relative to Peak	Thickness at a given part of the profile 5577 Å Light	Energy Loss
0.5 Maximum	5.8 km	11.6 km
0.25 Maximum	10.1 km	14.5 km
0.1 Maximum	15.0 km	24.0 km

SUMMARY OF AURORAL CONTRIBUTIONS TO 5577 Å NIGHT AIRGLOW

One of the purposes of this experiment was to determine whether bombardment by energetic particles might be a significant source of night airglow. Loosely speaking, this experiment determined what fraction of the 5577 Å night airglow at mid-latitudes can be regarded as a permanent aurora.

Three independent methods have been used in this determination. These are:

Method 1: comparison of the relative intensities of (N_2^+) 3914 Å and (OI) 5577 Å in airglow and aurora.

Method 2: accurate delineation of the altitude profile of 5577 Å and comparison with that likely to result from conceivable particle fluxes, and

Method 3: direct measurement of particles of such energies that they can penetrate to altitudes derived from the above profile.

From Method 1, the observed ratio of $\frac{Q\ (5577\ \text{Å})}{Q\ (3914\ \text{Å})}$ was more than 80:1 in the night airglow, whereas in auroras we have measured the ratio as about 2:1. Therefore less than three per cent of the airglow 5577 Å can be regarded as a permanent aurora.

From Method 2 no such quantitative comparisons can be deduced, since they involve many alternative pitch-angle distributions and energy spectra of precipitated electrons. Briefly, however, the altitude profile of 5577 Å is only about half as thick as that expected from such an electron flux as would give the thinnest profile and still retain feasible characteristics.

Method 3 indicates that the measured electrons with $E_e \geq 40$ kev could give less than 10^{-2} R of 5577 Å or less than 1 part in 10^5 of the observed brightness. Only electrons with this energy or more could penetrate to the depths observed in Method 2.

COMMENTS ON GALACTIC X-RAYS

In several rocket flights from White Sands, large-area geiger tubes have detected 'anomalous' radiation that has been ascribed to galactic X-rays (Giacconi et al. 1962, Gursky et al. 1963, Friedman 1964). Since the geiger tube type 8001 used here is not very dissimilar to those used in these galactic X-ray studies, it must be demonstrated that the fluxes reported here were really precipitated electrons uncontaminated by galactic X-rays. Conversely, of course, there is a need in such X-ray studies for adequate discrimination against precipitated electrons, as has been recognised (see Gursky et al. 1963).

The need for such discrimination was known to us during the design of this payload. It contributed, in part, to the choice of non-overlapping fields of view of the large area 8001 geiger and the two smaller geigers and to their orientation in the payload. In particular it also led to our use of the 6213 geiger with a broom magnet, since this would respond only to precipitated protons (which we did not expect to find in significant fluxes -- see O'Brien 1962), to electrons with $E_e \gtrsim 1$ Mev (which we also expected to be negligible -- see O'Brien 1962), and to galactic X-rays. The type 6213 geiger, without such a magnet, detects all this radiation and also electrons with 1 Mev $\gtrsim E_e \gtrsim$ 40 kev. Therefore any difference in their effective response, after subtraction of cosmic-ray background, must be due to precipitated electrons.

As discussed above, the resulting counting rates of the two detectors were (0.14 ± 0.05) c/sec for the open 6213 geiger and (0.01 ± 0.03) c/sec for the 6213 geiger with a magnet. There is a probability only of the order of one percent that both these rates could have been due to the same radiation flux. Therefore we conclude with some 99% confidence limits that the radiation measured by the open 6213 geiger was a flux of precipitated electrons with energy 1 Mev $\gtrsim E_e \gtrsim$ 40 kev. The equivalent flux was $\sim$ (7 ± 2) particles cm^{-2} sec^{-1} $sterad^{-1}$, or $\sim$ (40 ± 10) particles cm^{-2} sec^{-1} if isotropy over the upper hemisphere is assumed.

We have no means of proving that the type 8001 detected mainly precipitated electrons of slightly higher energy. However, as discussed above, the equivalent electron flux is about what would be expected for electrons with an energy spectrum like that of electrons trapped on the magnetic field line above Wallops Island. The altitude dependence (Fig. 4) is also consistent with a flux of such electrons. The counting rate should not increase further with altitude between $\sim$ 100 km and $\sim$ 167 km (as Gursky et al. 1963 suggested would be required of such particles) because the type 8001 field of view in this experiment remains within the loss cone, and it never views the pitch angles normal to $\vec{B}$ where particles can be trapped whose flux might well be expected to increase with altitude.

Several other arguments can be used to add plausibility to the above conclusion that the principal contribution in this experiment came from precipitated electrons rather than from galactic X-rays. For example, it might be assumed that the open type 6213 geiger was indeed responding to a localised source of X-rays. Then one can predict the counting rate of the much larger geiger tube flown at White Sands with a similar window thickness if it saw the same X-ray source. The type 6213 rates are spin averaged, whereas Giacconi et al. (1962) give their peak counting rate of $\sim$ 13/sec at a given azimuth. From the open 6213 rate one would predict that the geiger of Giacconi et al. (1962) would have had a peak rate of $\sim$ 100/sec or about eight times larger than was observed.

On the other hand, if we make a similar prediction from our type 8001 geiger tube we would estimate that the geiger of Giacconi et al. (1962) would have (see Fig. 5) a peak count rate of $\sim$ 100/sec at altitudes above $\sim$ 100 km, ie again eight times its actual rate. Thus it is apparent from both predictions that the flux of the 'anomalous' radiation was eight times larger over Wallops Island than over White Sands. This is the type of variation one might expect for precipitated electrons because of the different magnetic latitudes of the two observations (eg see O'Brien 1962) but it can be explained by galactic X-rays only if both our geigers viewed stronger sources than did Giacconi et al. (1962) and Gursky et al. (1963). The region of the celestial sphere viewed by our 8001 is shown in Fig. 6, and it is seen that the edge of its field of view included Scorpius, which has been reported as a very strong X-ray source (Friedman 1964) also viewed in the experiments of Gursky et al. (1963). An important point to note is that the fields of view of our 8001 and our 6213 geigers failed to overlap by $\sim$ 30°, so they could not have all seen the same X-ray source. Yet their rates are consistent with them viewing essentially the same radiation, and it therefore seems most reasonable to ascribe it to precipitated electrons with an energy spectrum similar to that of Van Allen electrons.

To summarise, comparison of the two type 6213 geigers reveals about a 99% probability that the dominant radiation was a precipitated electron flux. The assumption of isotropy over the upper hemisphere gives results consistent with the type 8001 geiger also detecting such electrons.

A plausible case can therefore be presented in favor of the hypothesis that our detectors at Wallops Island measured predominantly precipitated electrons. The flux of such electrons to be expected at White Sands is several times smaller and yet sufficient to still provide the geiger rates observed at White Sands in the X-ray studies. However, several arguments against electron contamination of the X-ray data have been presented by Giacconi et al. (1962) and Gursky et al. (1963) to which the reader is referred. Clearly the low statistical precision and the different X-ray efficiencies of the many geiger tubes employed make an accurate comparison of our data impracticable.

It is worthy of comment here that, conversely, studies of precipitated electrons, particularly in such small fluxes as found here, must be able to discriminate against galactic X-rays. The need to discriminate against solar and galactic X-rays is well known (cf O'Brien 1964, Van Allen and Frank 1962). Since the X-ray flux from the strongest source Scorpius is comparable with that from the quiet sun (Friedman 1964) it is possible that isolated cases of weak 'precipitation' observed from satellites in the past may have been contaminated by such X-rays. Geometric and solid-angle considerations would seem to argue against such galactic X-rays being a serious contaminant in the past observations. With most very thin-windowed geiger tubes such as used on satellite studies of particle fluxes (eg O'Brien 1964, Frank et al. 1964) and on space probes such as Mariner (Van Allen and Frank 1962) the efficiency of detection of penetrating charged particles is one to two orders of magnitude larger than that for detection of such X-rays.

It is also relevant to note that the intensity of 3914 Å measured in this experiment sets an upper limit of $\sim 10^{-2}$ ergs cm^{-2} sec^{-1} to the total flux of galactic X-rays from sources above the horizon (see Fig. 6). Galactic X-ray sources of the intensity of Scorpius (see Friedman 1964) must be included in comprehensive discussions of ionization and other processes in the terrestrial atmosphere at night.

DISCUSSION

A number of arguments have been developed over the years that would imply that airglow and aurora have different origins. For example, it is sometimes said that because airglow occurs at the equator particle precipitation could not be the cause. But since the causes of particle precipitation itself are not known (O'Brien 1964) and since erratic 'airglow' behaviour occurs even at very low latitudes this is not a conclusive argument. Again, it is sometimes argued that the weak or negligible relation between 5577 Å and magnetic activity indicates that particle precipitation is not involved. But any relations between 5577 Å in auroras and magnetic activity are simply empirical, with no theoretical causal relation, so again any generalization to lower latitudes would be dubious. The only conclusive way to resolve the problem is by a coordinated measurement such as reported here. The three methods used in this experiment conclusively demonstrated that less than three per cent of mid-latitude 5577 Å is excited by particle bombardment of the atmosphere. Other sources postulated to explain the airglow are discussed by Barth and Hildebrandt (1961) and elsewhere.

The upper limit to the 3914 Å emitted by N_2^+ from above ~ 85 km altitude is ~ 5 R. Since the lifetime of N_2^+ against dissociative recombination is so short in the nighttime upper atmosphere this implies that an adequate source of ionization must be continually present. From efficiency figures discussed in detail by Dalgarno (1964) this implies that the total ionizing radiation absorbed above ~ 85 km must be less than ~ 2×10^{-2} erg cm^{-2} sec^{-1}. It is of interest to note that this is very much the same as the energy flux dissipated in the lower atmosphere below ~ 30 km by cosmic rays.

Continuum nightglow in this portion of the spectrum is uncertain because it is so difficult to measure from the ground. This experiment would imply that such a continuum has a brightness less than 0.1 R/Å. The relevance of such a measurement is discussed by Chamberlain (1961).

As treated by Dalgarno (1964), measurement of the brightness of 3914 Å and thereby estimation of the flux of ionizing radiation is important to the subject of maintenance of the night-time ionosphere. Whereas the theory of Ivanov-Kholodny (1961 and elsewhere) required an ionizing flux of ~ 1 erg cm^{-2} sec^{-1}, we find a flux more than two orders of magnitude smaller. As discussed by Dalgarno (1964), either the nocturnal-ionization hypothesis or the theoretical treatment must therefore be rejected.

CONCLUSION

The experiment has conclusively demonstrated that less than three per cent of the mid-latitude 5577 Å night airglow can possibly be due to particle bombardment such as excites the same emission in auroras. The experiment places an upper limit of 5 R on the brightness of N_2^+ 3914 Å, and thereby implies that the total mid-latitude night-time ionizing radiation deposits less than (2×10^{-2}) ergs cm^{-2} sec^{-1} at altitudes above 85 km.

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FIGURE CAPTIONS

Figure 1: Counting rates of the 5577 Å and 3914 Å photometers as the rocket descended. Initially (phase A) they saw starlight, then in phase B they fell through the 5577 Å layer until (in phase C) they were underneath looking back up at the layer. The rocket turned over and they then (phase D) saw the airglow edge-on and much brighter as they viewed the horizon. For the range of starlight response see Fig. 2.

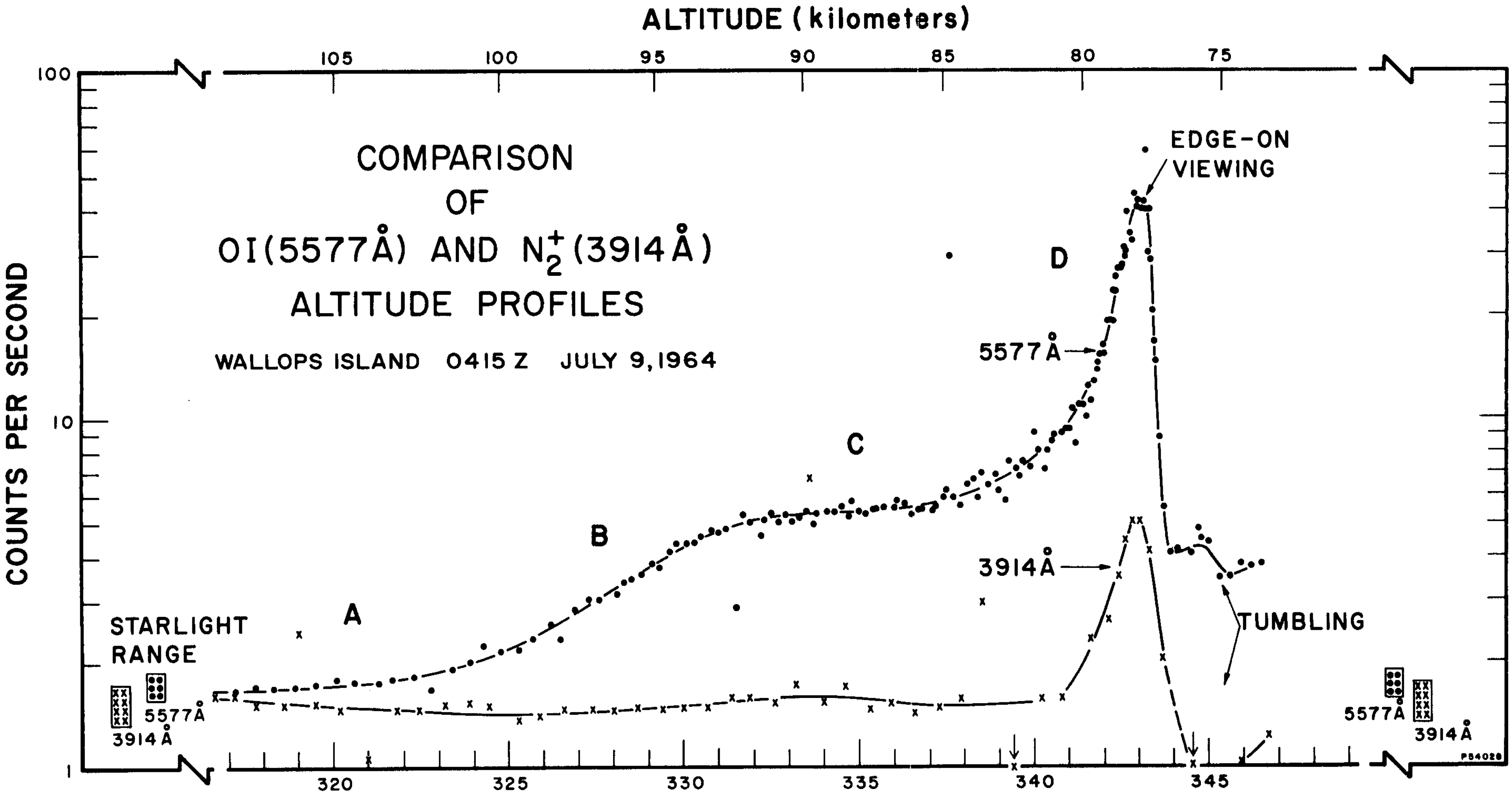
Figure 2: Illustration of the in-phase variations of counting rate of the two photometers when the rocket yawed and they viewed only starlight. Such data provide in-flight calibrations. Note the enhancement of 5577 Å but not 3914 Å as the rocket descended below ~ 100 km altitude and the photometers continued to look up.

Figure 3: Altitude profile of emission of 5577 Å night airglow. This is essentially the differentiation of phase B of Fig. 1.

Figure 4: Variation of counting rate of the 8001 geiger tube with altitude during ascent and descent. Note that essentially only cosmic rays were detected below ~ 80 km, and that the additional flux was absorbed between ~ 80 km and ~ 100 km.

Figure 5: Comparison of the atmospheric attenuation of counting rate in the galactic X-ray experiment (Giacconi et al. 1962) and in this experiment after the cosmic ray contribution was subtracted. The straight line A is a crude fit to the raw Wallops data (see the line in Fig. 4). Line B represents an adjustment to A to take account of the fact that the 8001 geiger tube here had an area of 6.7 cm^2, whereas that of Giacconi et al. had an effective area of 10 cm^2 (Gursky et al. 1963). Line C is a further adjustment because the 8001 had a window thickness of 4.0 mg cm^{-2} versus Giacconi's 1.4 mg cm^{-2}. The adjusted Wallops Island data therefore imply a flux eight times larger than at White Sands.

Figure 6: Celestial coordinates relative to this experiment. The egg-shaped curve delineates the edges of the field of view seen by the 8001 geiger tube for the average orientation of the rocket axis. The yaw of the rocket increases this by about five degrees. Gursky et al. (1963) and Friedman (1964) report the galactic center, the Crab, and a region near Scorpius to be X-ray sources.



ALTITUDE (kilometers)
105
100
95
90
85
80
75
100
10
1
COUNTS PER SECOND
COMPARISON
OF
OI(5577Å) AND N_2^+(3914Å)
ALTITUDE PROFILES
WALLOPS ISLAND 0415 Z JULY 9, 1964
EDGE-ON
VIEWING
A
B
C
D
5577Å
3914Å
TUMBLING
STARLIGHT
RANGE
5577Å
3914Å
320
325
330
335
340
345
TIME AFTER LIFT-OFF (seconds)

FIGURE 1.

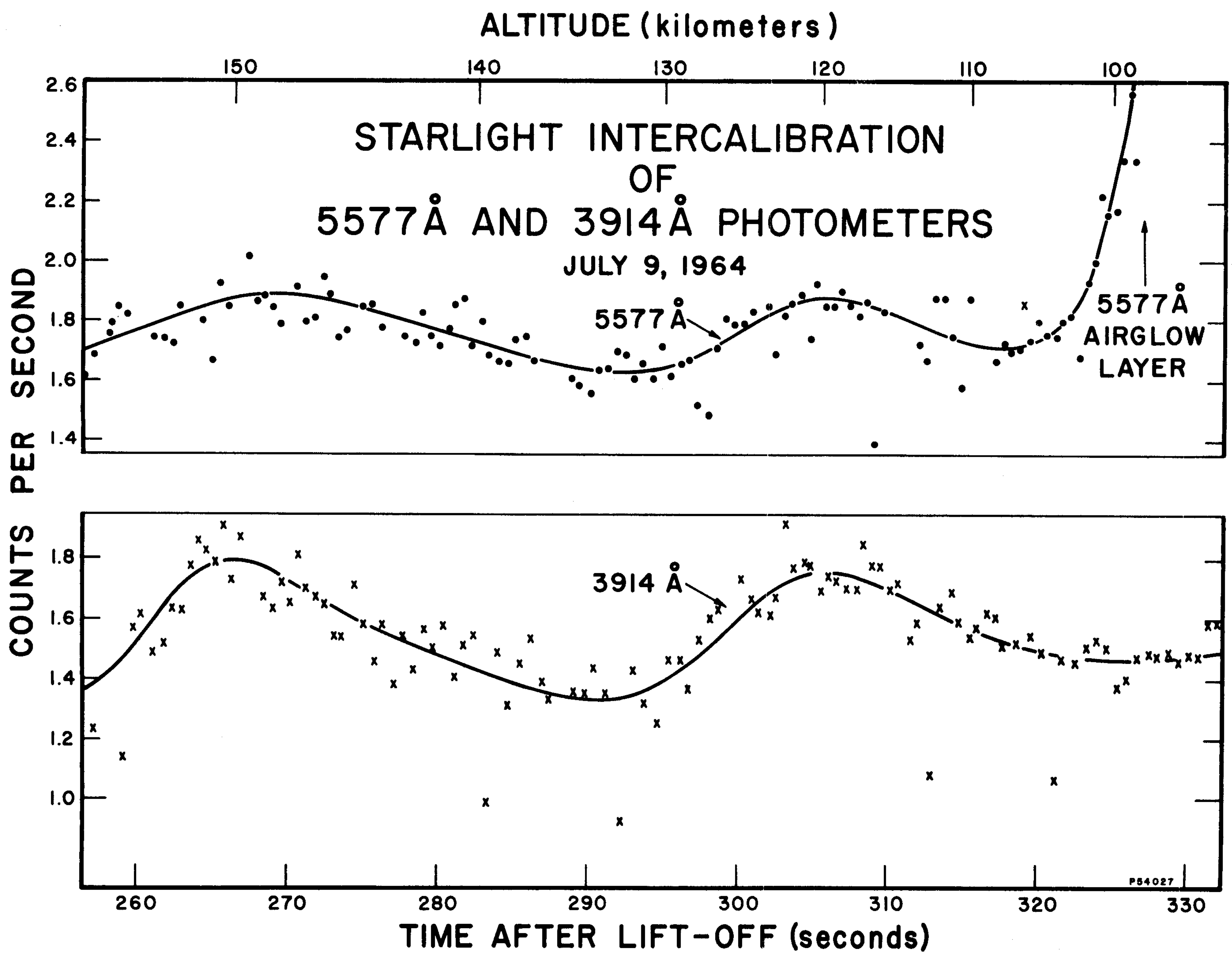
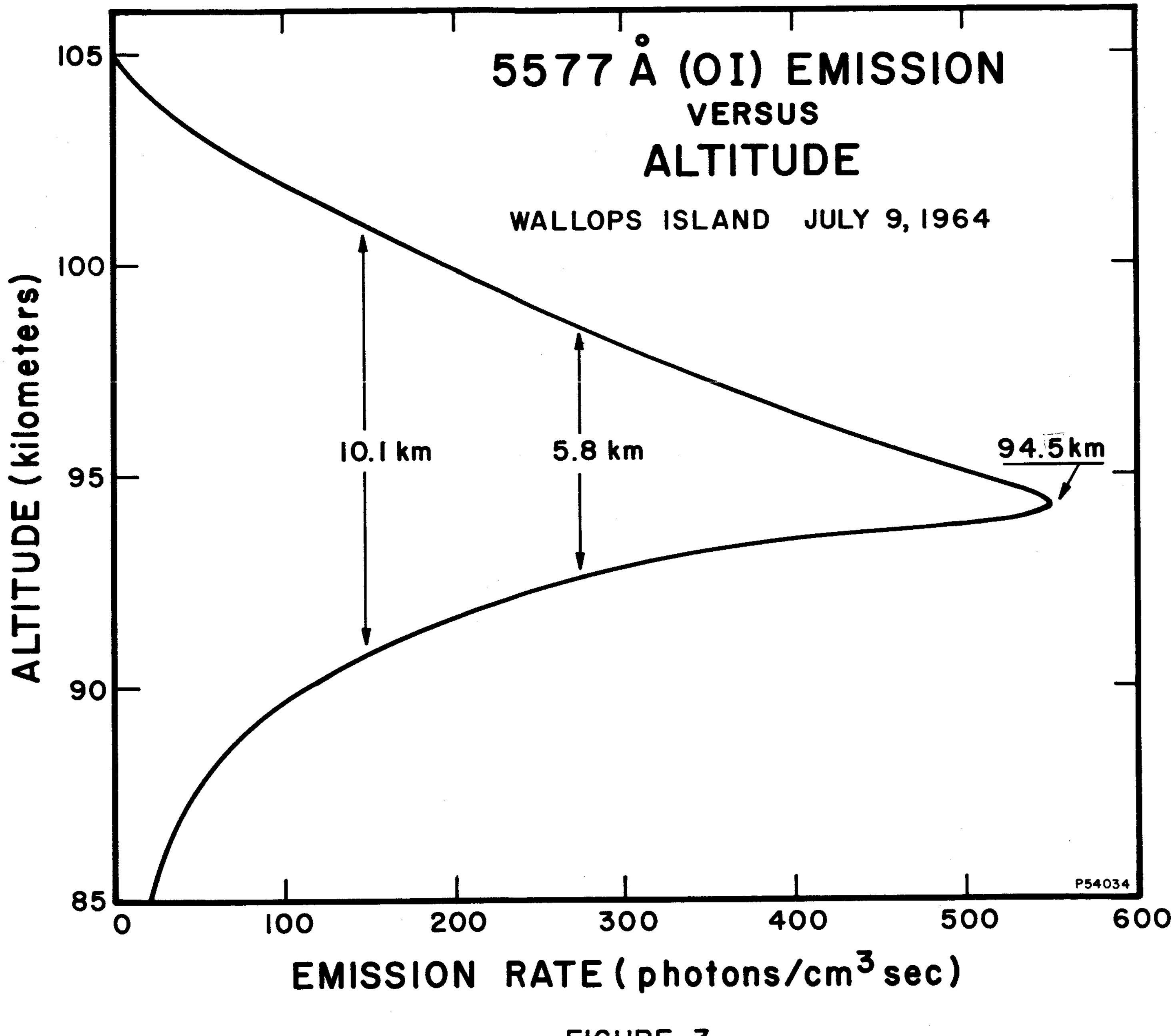

ALTITUDE (kilometers)
150
140
130
120
110
100
STARLIGHT INTERCALIBRATION
OF
5577Å AND 3914Å PHOTOMETERS
JULY 9, 1964
5577Å
5577Å
AIRGLOW
LAYER
3914 Å
COUNTS PER SECOND
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
260
270
280
290
300
310
320
330
TIME AFTER LIFT-OFF (seconds)
P54027

FIGURE 2.



5577 Å (OI) EMISSION
VERSUS
ALTITUDE
WALLOPS ISLAND JULY 9, 1964
10.1 km
5.8 km
94.5 km
ALTITUDE (kilometers)
105
100
95
90
85
0
100
200
300
400
500
600
P54034
EMISSION RATE (photons/cm³ sec)

FIGURE 3.

GEIGER COUNTING RATE VERSUS ALTITUDE

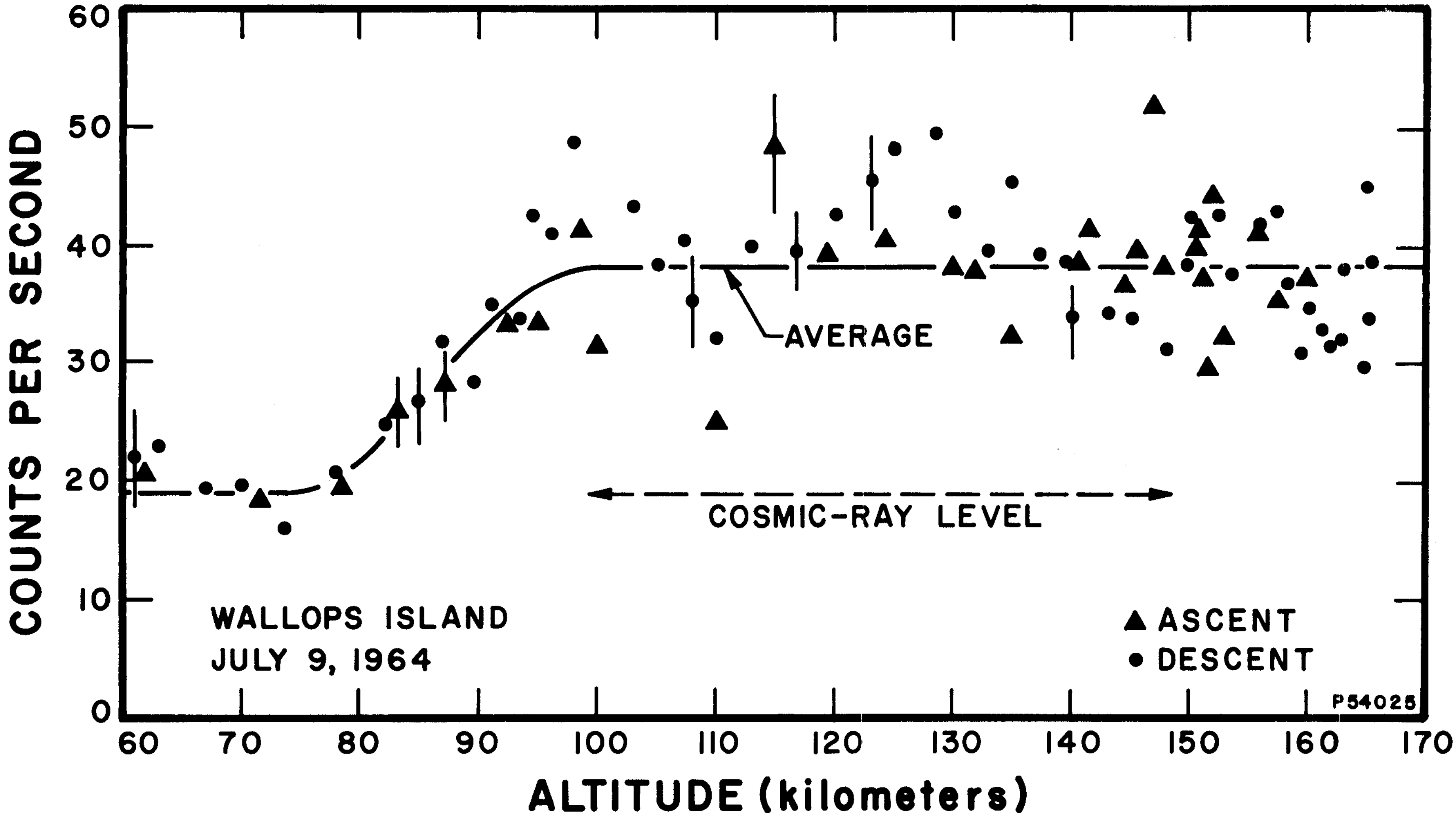


FIGURE 4.

ALTITUDE PROFILES

GALACTIC X-RAYS AND PRECIPITATED ELECTRONS

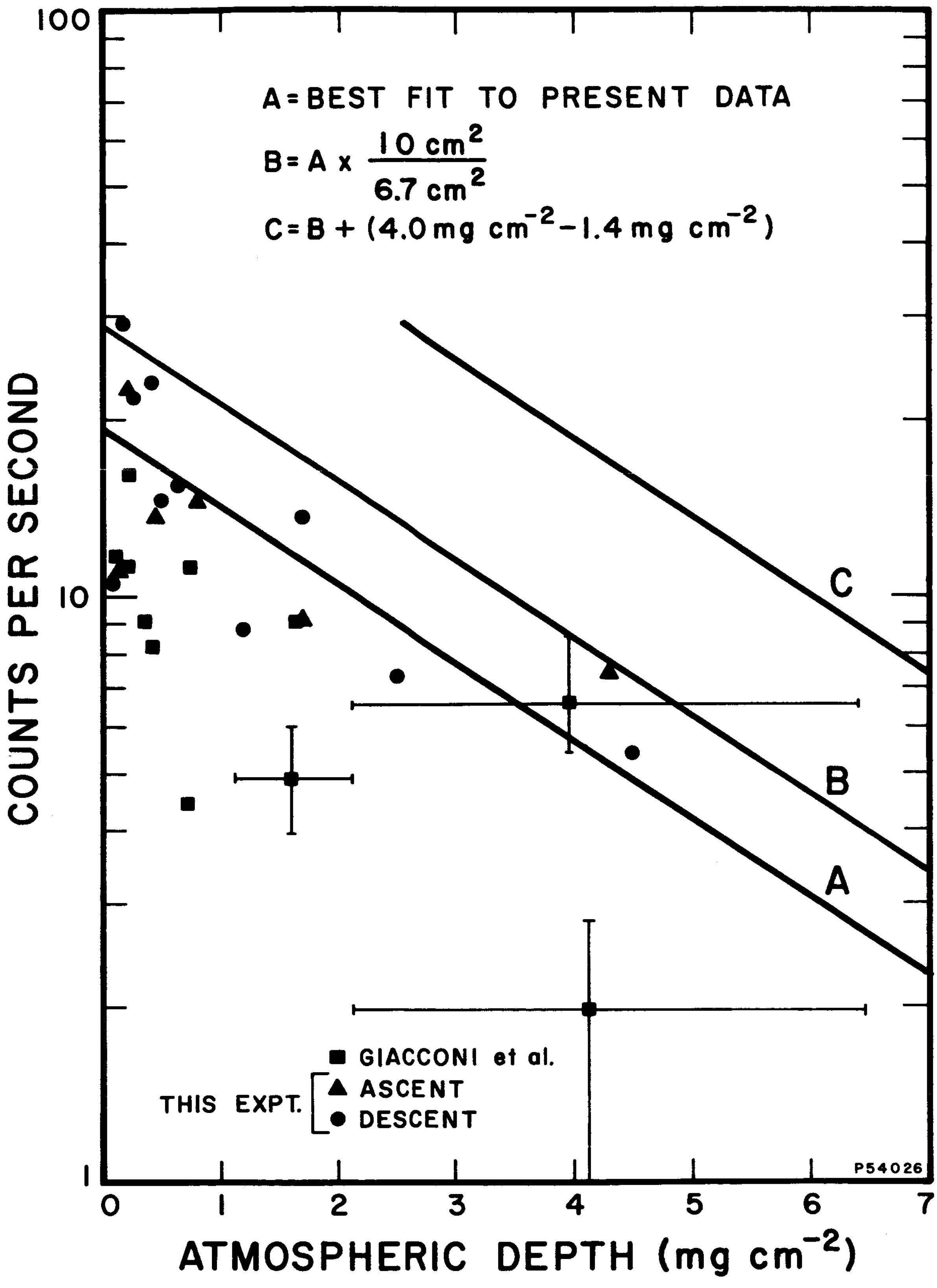


FIGURE 5.

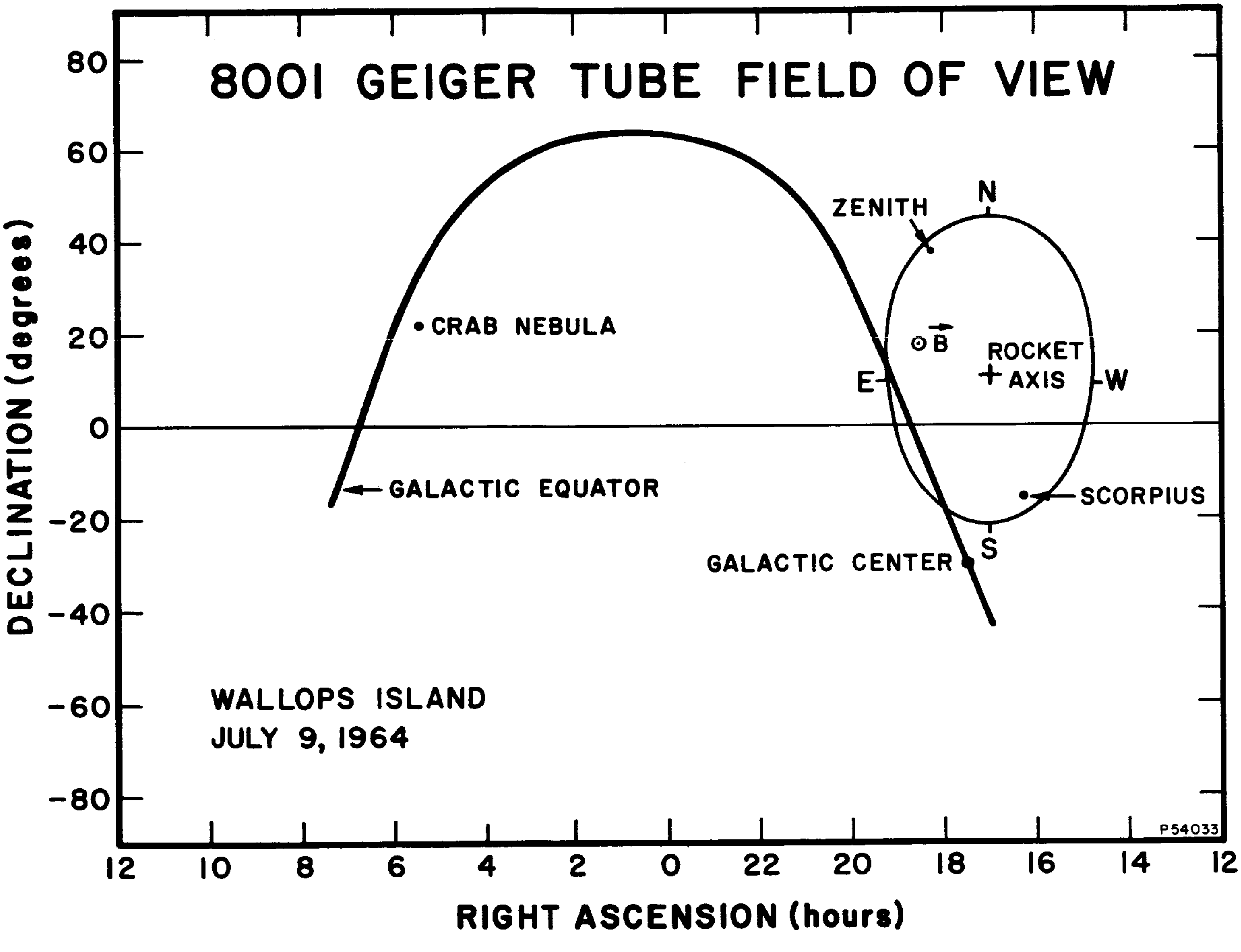

8001 GEIGER TUBE FIELD OF VIEW
80
60
40
20
0
-20
-40
-60
-80
DECLINATION (degrees)
12
10
8
6
4
2
0
22
20
18
16
14
12
RIGHT ASCENSION (hours)
ZENITH
N
E
W
S
CRAB NEBULA
$\odot\vec{B}$
ROCKET
AXIS
GALACTIC EQUATOR
SCORPIUS
GALACTIC CENTER
WALLOPS ISLAND
JULY 9, 1964
P54033

FIGURE 6.